# FEM Study of Precast Pile in Soft Bangkok Clay Subjected to Adjacent Embankment

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***Abstract—*** *Behavior of a single pile subjected to lateral loading in soft Bangkok clay has been studied using finite element model. The 2D plane strain finite element model was generated, and consisting of 35 m depth Bangkok soil profile with a precast concrete pile installation. Different pile sizes of 150x150mm to 400x400 mm and pile length of 5 m to 30 m are considered. The strip uniform load is applied at 1-m adjacent to the pile, which induced lateral load, and causes pile deflection, shear and bending moment in the pile shaft. A total of 135 cases were simulated and the plastic point development stages and fixed end and free end pile behaviors were classified. The maximum surcharge load for critical bending moment and pile top displacement charts were produced for engineering practices.*

***Key words: lateral loaded pile, Bangkok soft soil, pile deflection, finite element model***

## 1.0 Introduction

Bangkok city is located in Chao Phraya delta area which consists of a thick soft clay deposit. For bearing capacity and settlement control, pile foundation is commonly used to transfer the vertical load to a firm stratum. For typical low-to medium-rise buildings constructed in Bangkok and its vicinity, precast concrete piles are practically used for the foundation support. However, with urban expansion, new construction activities could induce lateral load to existing pile foundations, causing pile deflection, axial load capacity reduction, and could lead to exiting structural damage and failure.

Laterally loaded pile behavior has been studied through centrifuge model, full-scale observation, and computer models, and the laterally loaded pile performance could be analyzed by Brom's method [3] elastic beam on spring support or p-y method [5],[10] ,[13], [14],[11],[2] and finite element approach [6] ,[7] ,[16]. Recently, finite element method (FEM) is undertaken in research and engineering practices because the method could provide soil-pile response, and various material models and stages of construction could be taken into account. Typical soil models used in the FEM analysis include linear and non-linear elastic model, Mohr-Coulomb model, and Modified-Cam Clay model [16]. Two-dimensional plane strain condition is normally used for many applications. However, the study of laterally loaded pile in soft Bangkok clay is limited. Only large-scale tests for lateral load resistance on large bored pile had been conducted for infrastructure specification, but the results are classified. Only few experiment data and research study are available [4].

To understand the laterally loaded pile behavior, a finite element method is studied for precast concrete piles in soft Bangkok clay subjected to adjacent load. The modes of failure, and pile response, including pile deflection, induced shear and moment, were observed and critical surcharge load could be determined for different pile sizes and pile lengths.

## 2.0 Finite element model

Plaxis 2-D program utilized to construct the finite element model of lateral loaded pile in Soft Bangkok clay. The 2-D model is assigned as plan strained condition, and consists of a precast concrete pile installed in soft Bangkok clay adjacent to the embankment as showed in Fig.1 .The model has a width of 124 m and the depth of soil foundation is 30 m. The embankment was placed on the ground surface with a base width of 16 m and induced vertical load of 37 kPa. The precast concrete pile is placed at 1 m away from the embankment toe.

The Mohr-Coulomb material model is assigned for the soil foundation. The concrete pile is modeled as a linear elastic material. The fine mesh, consisting of 15-node triangular element, is generated for the soil foundation. The concrete pile is assigned as a plate element. The soil-pile interface is an elasto-plastic model and the interface strength property is governed by soil-pile shearing resistance. Restrained condition in x and y direction is assigned at the bottom boundary and restrained condition in x direction is assigned for the side boundary of the model.

After model geometry was generated, stages of construction are assigned, starting from $K_o$ soil foundation condition, pile installation, and followed by embankment construction and vertical stress application. The vertical stress is applied on the top of embankment with an increment of 4 kPa to 20 kPa until the failure is reached

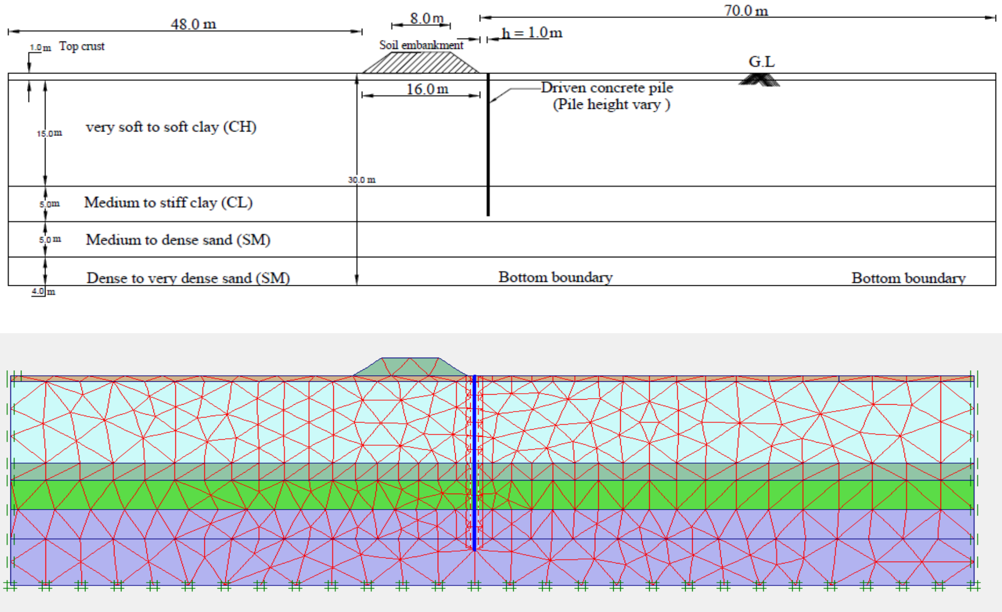


Fig.1 Model geometry and boundary condition

## 3.0 Input parameter

The Bangkok subsoil exploration data collected as per [1] and used to generate soil profile model, see Fig.2. Zone E is selected due to very low shear strength and high compressibility of a thick soft clay deposit. The soil profile consists of 5 layers which are top crust (1 m thickness), very soft to soft clay (14 m thickness), and medium to stiff clay (5 m thickness), medium to dense sand (5 m thickness) and dense to very dense sand (10 m thickness). For each layer, the Mohr-Coulomb soil parameters are assigned as summarized in Table 1. These selected parameters are determined from available data and semi-empirical relationship [1].

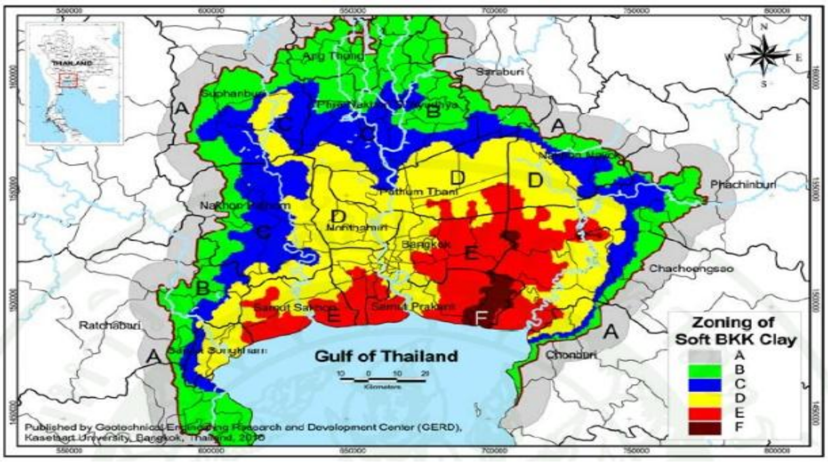


Figure 2 : Bangkok soft soil zones[1]

Table 2 presents the precast concrete pile model parameters. Three sizes of square pile were studied including 150x150mm, 300x300mm and 400x400mm. The pile length varies from 6 m, 12m, 17m, 26, and 30 m. The pile properties are illustrated in Table 2, including cross-section area, elastic modulus (E), moment of inertia (I), safe axial load, bending moment capacity (BM) and shear strength capacity (V). Note that, the maximum bending moment and maximum shear force capacity were determined from typical reinforced driven pile manufactured in Thailand according to ACI -318. The soil-pile interface parameters ($R_{inter}$) is assigned as 0.5 and 0.6 for cohesive soil and granular soil, respectively [8] .The value of modulus of elasticity of piles (E) was taken into account for a single pile.

Table 1: Soil properties [1]

| Depth | Layer thickness | Soil type | E | c' | ϕ' | Density | $s_u$ | ν |
|---|---|---|---|---|---|---|---|---|
| ( m ) | ( m ) | | kN/m² | kN/m² | (deg) | kN /m³ | T/m² | |
| 0 - 1m | 1 | Top crust | 12500 | 1 | 30 | 15.5 | 2.5 | 0.3 |
| 1m -15m | 14 | Very soft to soft clay (CH) | 7500 | 4 | 29 | 15 | 1.9 | 0.4 |
| 15m-20m | 5 | Medium to stiff clay (CL) | 15000 | 12 | 34 | 16.5 | 3 | 0.3 |
| 20m-25m | 5 | Medium to dense sand (SM) | 25000 | 1 | 33 | 17.5 | 4 | 0.3 |
| 25m-35m | 10 | Dense to very dense sand (SM) | 37500 | 0.65 | 30 | 19.0 | 7.5 | 0.3 |

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Table 2 : Precast concrete pile properties

| Size | Cross section | Safe axial load | E | I | Bending Moment capacity | Shear capacity |
|---|---|---|---|---|---|---|
| (mm) | (m²) | (Tons) | (kPa) | (m)⁴ | (kNm) | (kN/m) |
| 150x150 | 0.0225 | 32 | 28,286,929.84 | $4.21 \times 10^{-5}$ | 4.8 | 12.2 |
| 300x300 | 0.09 | 126 | 2,8286,929.84 | $6.75 \times 10^{-4}$ | 32 | 43 |
| 400x400 | 0.16 | 221 | 2,8286,929.84 | $2.1 \times 10^{-3}$ | 45.3 | 86 |

Note : Concrete strength ( f 'c = 350 ksc), density = 24 kN/m³ , Poison ratio = 0.15

The slope stability analysis of soil embankment in the model carried by the limit equilibrium method (spencer method) and factor of safety showed as more than 1 (F.S>1) moreover, plastic failure occurred at the same applied vertical stress.

The finite element model was validated with a full scaled driven pile experiment results [19].The results of the experiment revealed that the lateral displacement of pile and induced bending moment and shear force. The investigation was done with 3 testing piles (diameter = 300 mm & length = 13 m) for 3 lateral loads which applied horizontal direction to the head of the pile (reaction pile had been used).The pile head displacement was determined from visual inspections. FEM model was generated in Plaxis 2D as per [19] and determined the pile head displacement and compared as shows in Fig 2.1.

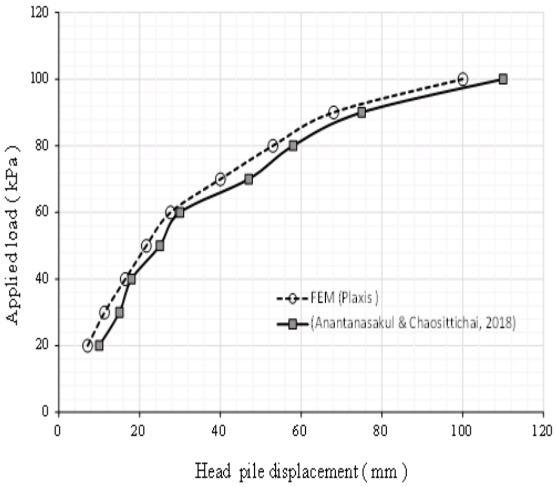


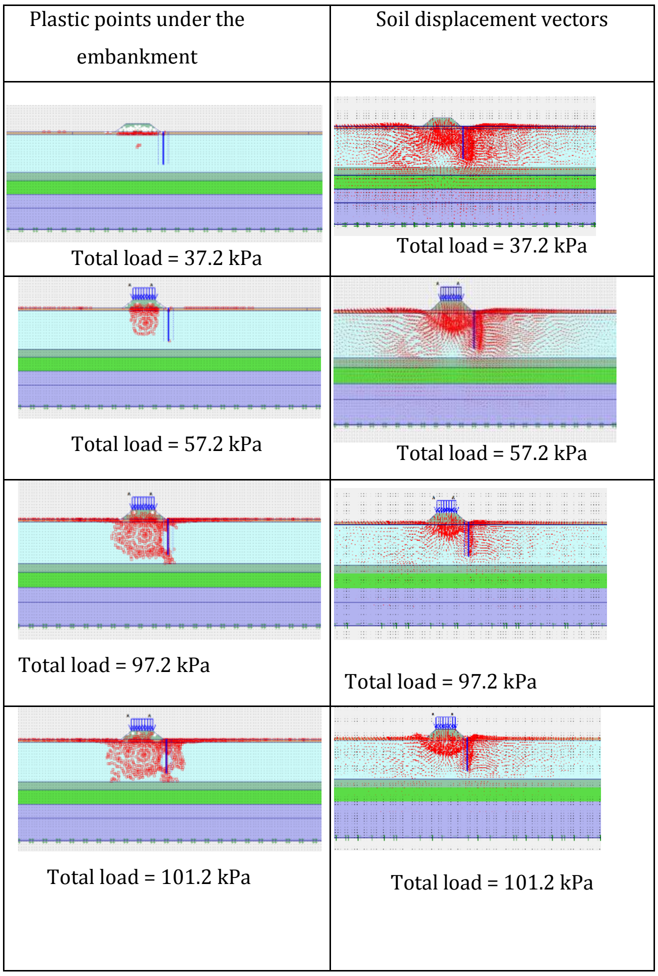

Fig 2.1 Pile head displacement, comparison of field test results [19] with FEM results

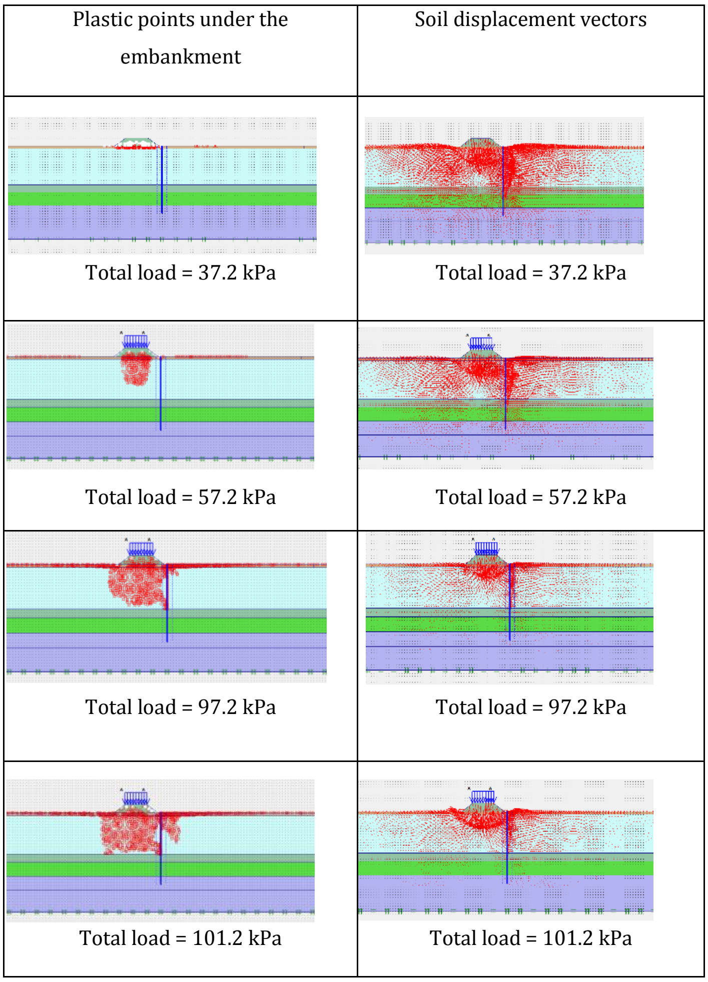
## 4. Results

### 4.1 Stages of plastic point development

A total of 135 cases had been analyzed for 3 pile sizes and 5 pile lengths, and the results show that the soil-pile behavior could be classified into 4 main stages, including (i) elastic stage, (ii) contained plastic stage underneath the embankment, (iii) plastic point development around the pile stage, and (iv) fully plastic stage or soil-pile failure, see Fig.3.

Elastic stage occurs when the applied vertical stresses on the ground surface is relatively low ($\Delta\sigma_v < 40$ kPa). As a result, the soft clay soil layer is under elastic condition, while plastic point only appears in the top crust layer. At this stage, the pile top is displaced within 2 to 3 cm. As the applied vertical stress increases, the plastic point starts to develop in the soft clay layer, however, the plastic points are contained underneath the embankment. The contained plastic stage underneath the embankment is observed when the $\Delta\sigma_v$ value is in the range of 40 to 80 kPa, and the pile top is displaced approximately 5 cm. Further increase in $\Delta\sigma_v$,the plastic point starts to develop around the pile. At this stage ($\Delta\sigma_v$ = 80 to 90 kPa), a noticeable lateral pile displacement is observed in increasing rate, and induced moment in the pile reaches the maximum value. When the $\Delta\sigma_v$ is higher than 90 kPa, the plastic points start to develop on the right side of the pile until the failure is reach.



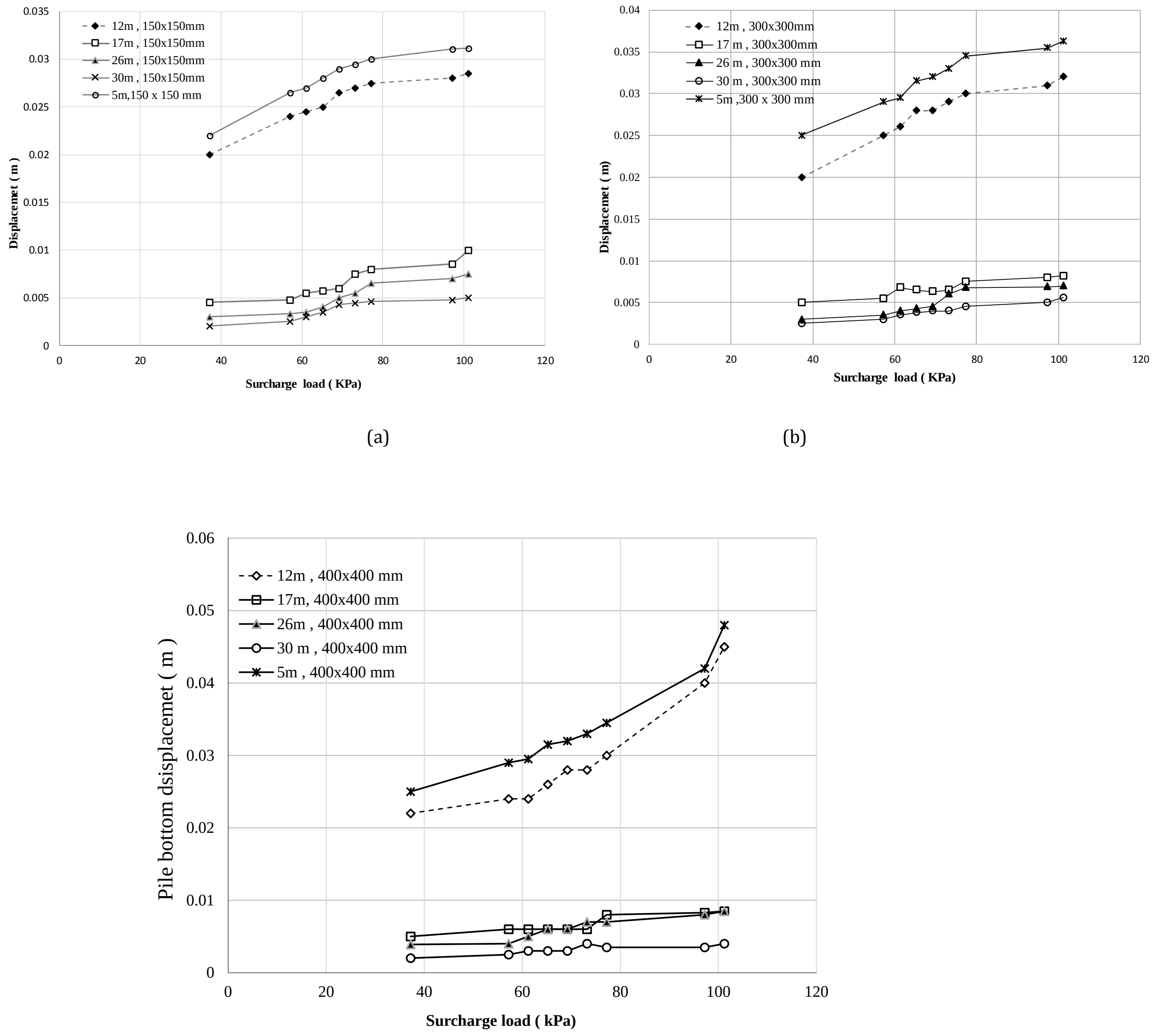




( a ) ( b )

Figure 3. Four stages of soil-pile behavior for (a) Friction pile ( L=12m , 400x400 mm)
(b) End bearing pile (L=26m , 400x400mm)

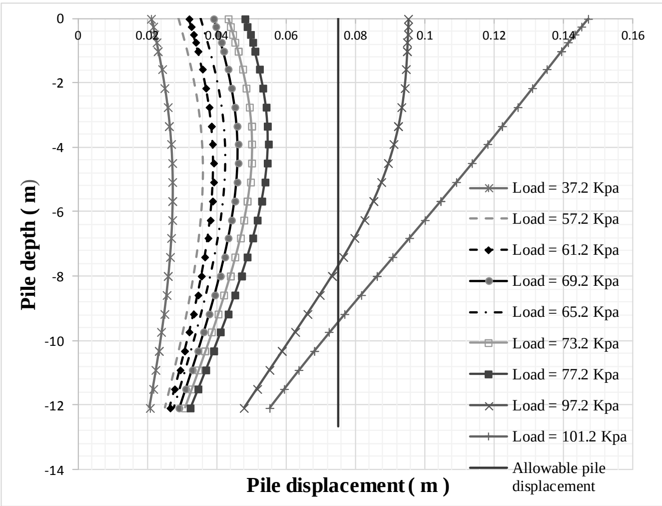
### 4.1 Free-end pile vs Fix-end pile behavior

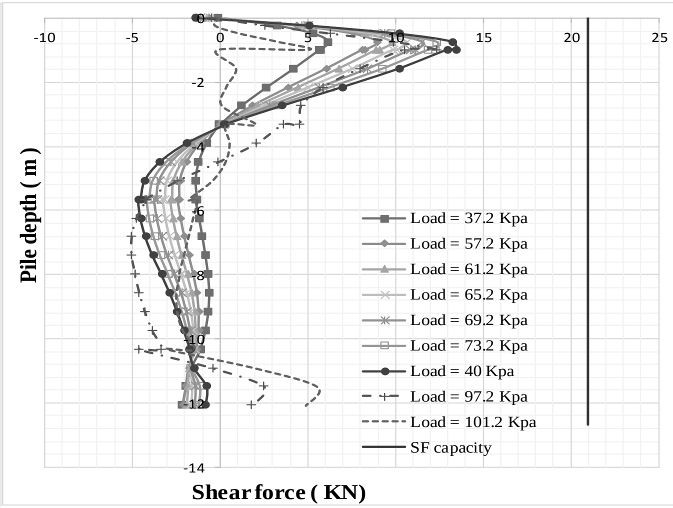
Considering pile deformation and induced moment results, the behavior of lateral loaded pile in Soft Bangkok clay could be classified into 2 categories, as described by Brom (1964), which are (i) free-end pile and (ii) fix-end pile. The free-end pile behavior is observed when the pile length (L) is less than 15 m in which the pile bottom is rest in soft clay layer. The fix-end pile behavior could be noticed when the pile bottom is rested in medium to stiff clay and medium to dense sand (L > 15m). For free-end pile behavior, the pile bottom is moved in a relatively high magnitude (2 – 3 cm) comparing to the fix-end pile behavior (0.2 to 0.8 cm), as showed in Fig. 4. In addition, the pile shaft displacement vs pile depth plot has one curvature for the free-end pile, whereas 2 curvatures can be observed in the fix-end pile, as illustrated in Figs.5a & 6a. As consequence, for free-end pile, the induced moment in pile shaft is in positive direction, whereas for fix-end pile, the induced moment has positive and negative direction.



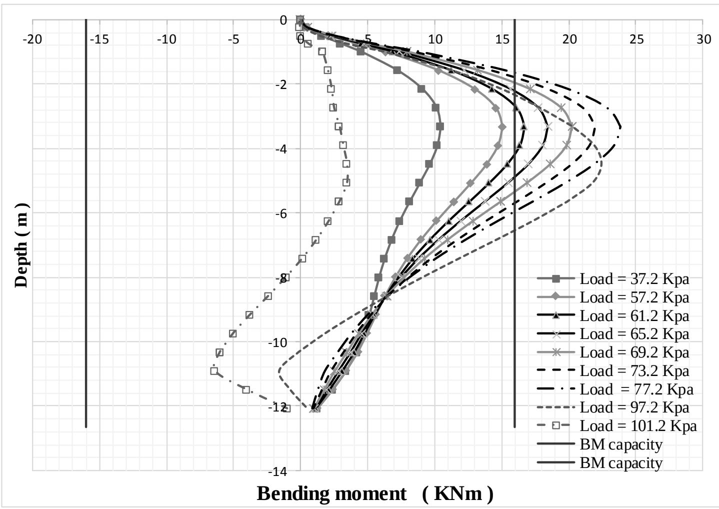

( c )

Figure 4. Pile bottom displacement vs surcharge load in 3 pile sizes
(a) 150 x 150 , (b) 300 x 300 & (c) 400 x 400

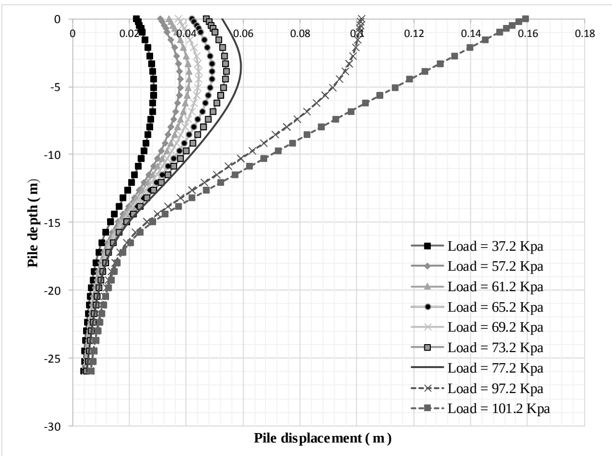



(a) (b)




( c )



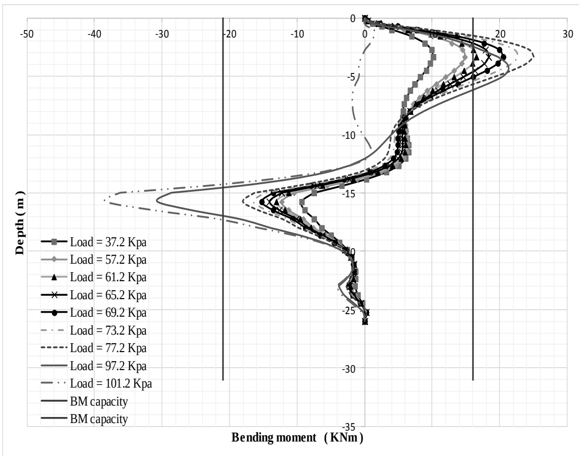
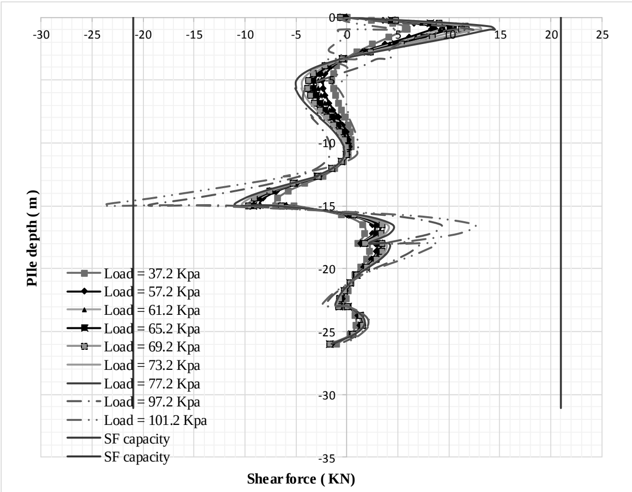




Fig.5 Free end pile behavior 300x300 mm , L=12m ( a ) lateral pile displacement ( b ) Shear force diagram ( c ) Bending moment diagram

( a ) ( b )



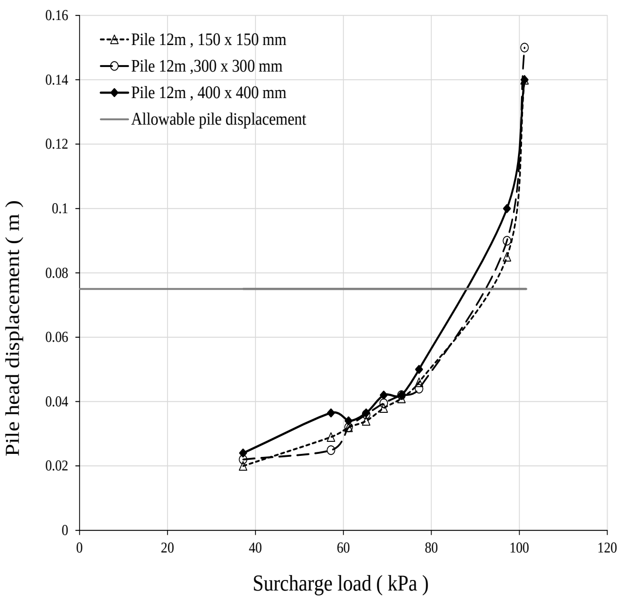

( c )

Fig.6 An example of fix end pile behavior (300x300 , L=25m )

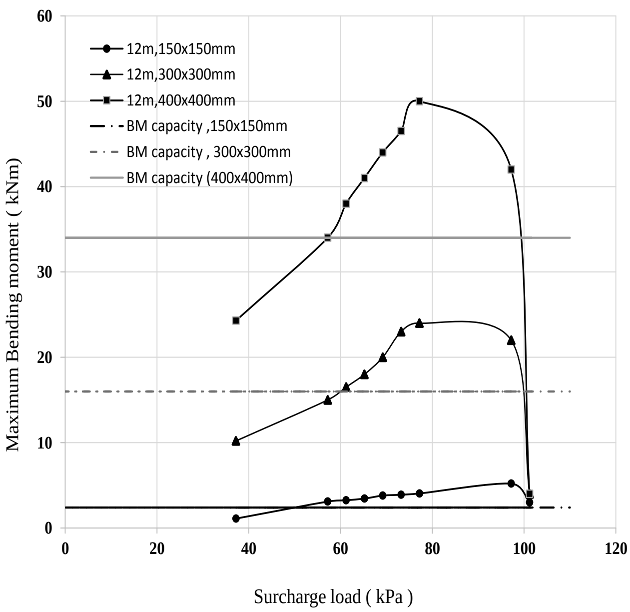
(a) Pile displacement (b) Bending moment diagram (c) Shear force diagram

### 4.3 Critical modes of failure

Relationships of induced lateral stress, lateral deflection, shear and bending moment in the pile are illustrated in Figs. 5 and 6 for free-end, and fix-end pile behavior, respectively. Note that the maximum allowable horizontal displacement (at the pile top) and maximum bending moment capacity, and maximum shear force capacity lines are plotted in the figures. The lateral loaded pile could fail by (i) capacity of precast concrete pile, i.e. bending and shear failure, and (ii) pile tip lateral movement due to soil deformation. The FEM analysis results showed that for free-end pile, the maximum moment occurs at 3 m below the ground surface, and maximum shear occurs at 1.5 m below the ground surface. For the fix-end pile, the positive maximum moment, and negative maximum moment are observed at 3m, and 16 m below the ground surface respectively. The zero moment is found at 14 m near the bottom of soft clay layer. The positive maximum shear force appears at 1.5 m below the ground surface, and the negative maximum shear force is found at 15 m below the ground surface.




( a )

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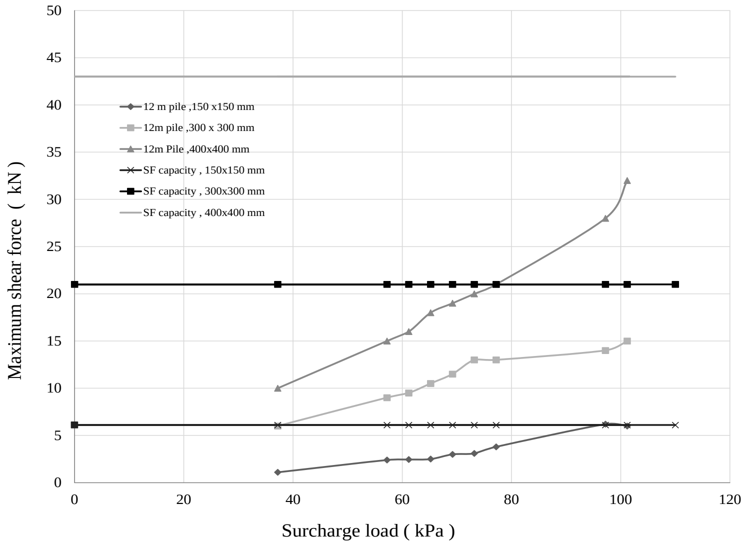


( c )

Fig.7 (a) Pile top displacement (b) maximum shear &

(c) maximum moment vs applied surcharge load ($\Delta\sigma_v$) for different pile sizes and pile lengths.

Figure 7 presents the relationship of pile top displacement, maximum shear and maximum moment and applied vertical load ($\Delta\sigma_v$) for different pile sizes and pile lengths. The critical pile top displacement [$(c_{ritical})_\Delta$ =7.5 cm], and critical bending moment capacity of the piles [$(c_{ritical})_{BM}$ = 4.8 to 45.3 KNm] are also illustrated in Fig.7. Note that the critical shear capacity of the pile [$(c_{ritical})_S$] is in the range of 12 to 86 KN/m for 150x150 mm to 400x400 mm pile, respectively. The results reveal that the lateral loaded pile could possible fail in moment and displacement modes.

Figure 8 represent a critical mode of failure chart for lateral loaded precast concrete pile in soft Bangkok clay. The chart consists of typical reinforced concrete pile size of 150x150, 300x300 and 400x400 mm, with the pile length ranging from 6 m to 30 m. For the study outcome, the critical mode of failure is governed by the induced moment. The [$(c_{ritical})_{BM}$] is 56 kPa to 60 kPa which is lower than the [$(c_{ritical})_\Delta$] which is in the rage of 85 kPa to 88kPa

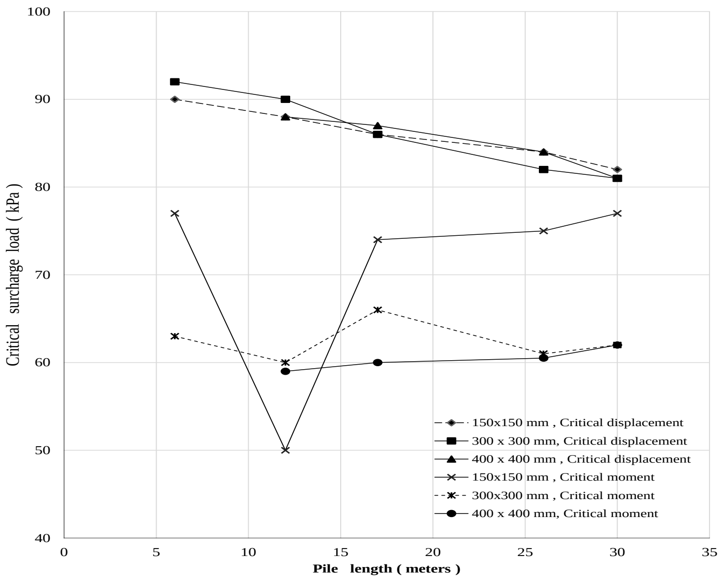


Fig.8 Critical surcharge load vs. pile lengths

## 5. Conclusions

This research is to study the reinforced concrete pile behavior in soft Bangkok clay which was subjected to adjacent loading. The Bangkok soil profile and typical precast concrete pile data were utilized for 2D finite element model. The 35-m depth subsoil profile, including 14-m thick of soft Bangkok clay, was modeled as Mohr-Coulomb. Three sizes of square concrete pile are considered, including 150x150mm, 300x300mm and 400x400mm, and the length varies from 6 m to 30 m. The uniform strip vertical stress is applied at 1-m away from the pile top. The vertical stress is increased until the failure occurs. The FEM study results could demonstrate plastic point development stages, pile behavior classification (fix-end and free-end), and critical modes of pile failure, as following.

1) The pile-soil interaction can be revealed by plastic point development in soil foundation and lateral displacement and induced moment of the pile. Four main stages were classified, including (i) elastic stage ($\Delta\sigma_v$ < 40 kPa), (ii) contained plastic stage underneath the embankment (40 < $\Delta\sigma_v$ < 80 kPa), (iii) plastic point development around the pile (80 < $\Delta\sigma_v$ < 90 kPa), and (iv)fully plastic stage or soil-pile failure ($\Delta\sigma_v$ > 90 kPa).

2) The soft Bangkok clay soil profile has an influence on the lateral loaded pile performance which could be classified into free-end pile and fix-end pile behavior. When the pile length is shorter than 15 m and the pile bottom is rested in the soft Bangkok clay, the pile behaves as free-end pile. In contrast, when the pile length is longer than 15 m (i.e. the pile bottom is rested in medium to stiff clay and medium dense to dense sand), the pile behaves as fix-end pile.

3) For free-end pile, the pile bottom is moved in a relatively high magnitude (2 – 3 cm) comparing to the fix-end pile behavior (0.2 to 0.8 cm). For free-end pile, the positive maximum moment occurs at 3 m below the ground surface (about 1/4 of soft Bangkok clay layer thickness). For fix-end pile, the positive maximum moment, and negative maximum moment are observed at 3m, and 16 m below the ground surface, respectively. The zero moment is found at 14 m near the bottom of soft clay layer followed by medium to stiff clay layer.

4) Two critical modes of pile failure are observed, which are pile top displacement failure ($\Delta_{critical}$ = 7.5 cm) and bending moment of pile shaft failure ($Cr_{itical}$ = 5 to 45 kNm). The critical surcharge load induced pile top displacement failure $[(c_{ritical})_{\Delta}]$ and the critical surcharge load induced bending moment failure $[(c_{ritical})_{BM}]$ were determined. Both $[(q_{critical})_{\Delta}]$ and $[(c_{ritical})_{BM}]$ are mainly influenced by the pile length (L). For L = 5 to 30 m, the $[(c_{ritical})_{BM}]$ is 56 kPa to 60 kPa which is crucial than the $[(c_{ritical})_{\Delta}]$ which is in the range of 85 kPa to 88 kPa.

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